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Interface reconstruction in GaAs/AlAs ultrathin superlattices grown on (311) and (001) surfaces

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$A^{III}B^{V}$ semiconductor superlattices (SLs) are widely used for electronic and optoelectronics devices. The properties of the SLs depend on the interface structure. For atomic scale studies of the interfaces and the quantum objects the scanning tunnelling microscopy (STM) and high resolution electronic microscopy (HREM) are usually used. Raman spectroscopy is non-destructive technique for studies of the SLs [1]. In recent time the SLs grown on not only traditional (001), but on high-index surfaces are widely studied [2]. One of the interesting problem is how the surface reconstruction affects on atomic structures of the quantum objects. For instance, in some growth conditions, the GaAs (001) surface appeared to be (2×4) reconstructed [3], and (311)A surface appeared to be corrugated [2] or (1×8) reconstructed [4]. Recently, it was observed, that after deposition of GaAs submonolayer cover on (001)-(2×4) reconstructed GaAs surface, the GaAs islands, containing 6 or less Ga dimers, are formed [5]. The $GaAs_nAlAs_m$ superlattices (SLs) grown on (311)A, (311)B and (001)-(2×4) surfaces was studied using Raman spectroscopy, $12 \geq n \geq 1$, $m = 8$ monolayers (mls) in (311) direction. The phonon spectra were studied using the Raman spectroscopy technique. The Raman spectra were registered at room temperature in quasi-backscattering geometry using the Ar laser.

The Raman spectra of SLs grown on (311)B and faceted (311)A surfaces are shown in Fig. 1(a,b). Due to symmetry selection rules, the TO_y and TO_x modes (atoms vibrate along the crystallographic directions Y and X, along and transverse to GaAs quantum wires) are observed in polarisation geometries $Z(YY)\bar{Z}$ and $Z(YX)\bar{Z}$ respectively. In Fig. 1(a), one can see the splitting of confined TO modes of first order $TO1_y$ and $TO1_x$. The splitting increases with decreasing of average thickness of GaAs layers. The Raman spectra of (311)B SLs grown in the same conditions and have the same thickness of layers as in the case of the (311)A surface are swown in Fig. 1(b). It is seen, that in this case the effect of splitting of TO modes is negligible. In the case of (311)A SLs the splitting sharply increases when the average thickness of GaAs layers is equal or less than the height of facets in one of the model of (311)A surface reconstruction (6 monolayers) [2]. This fact can be an indirect evidence of the quantum wire-like growth model [2]. And indeed, the cross section HREM data of (311)A SLs confirms this model, the modulation of GaAs and AlAs layers in (01-1) direction with period about 3.0 nm was observed [6].

The experimental Raman spectrum of GaAs/AlAs SL grown on (2×4) reconstructed surface is presented in Fig. 2. The thickness of GaAs layers was 0.6 ml, the full period was 6 mls, the SLs contains 400 periods. As one can see, peak associated with the scattering on GaAs-type localized LO phonons has distinguishable triplet structure. The observed structure of Raman spectra did not change when the probing laser beam was scanned the SL

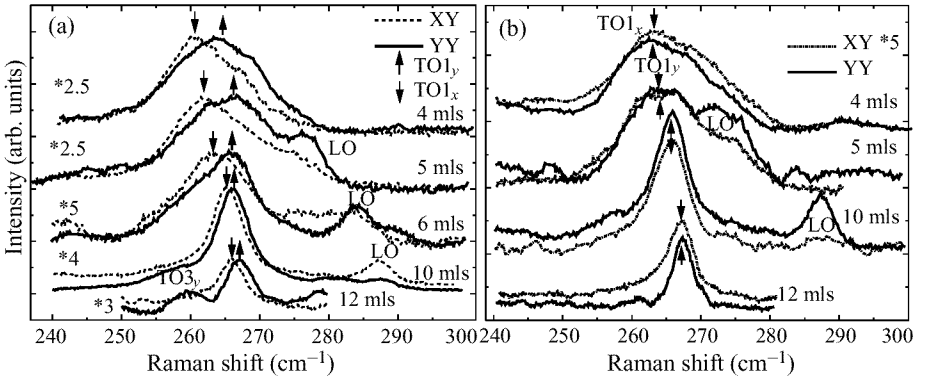

Fig. 1. Raman spectra of GaAs/AlAs SL with various thickness of GaAs layers grown on: (a) (311)A faceted surface, (b) (311)B surface.

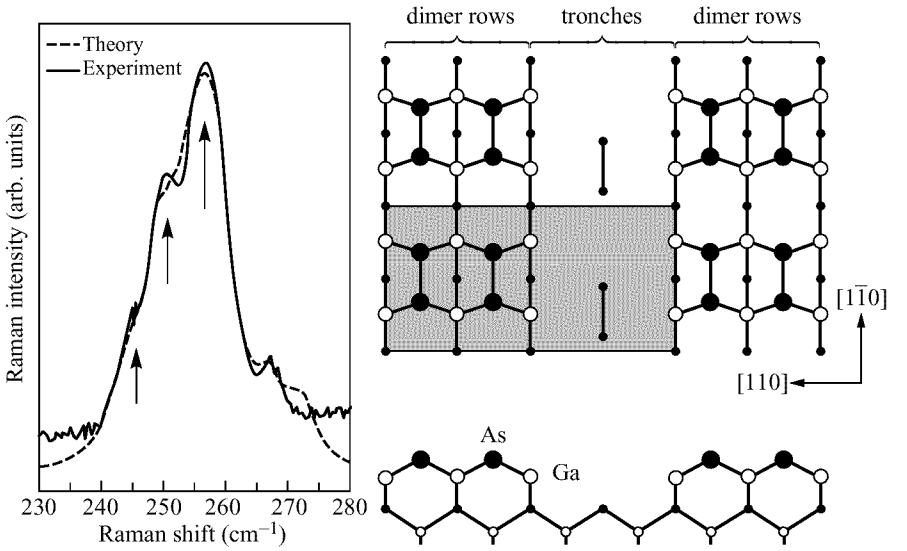

Fig. 2. The experimental ($\lambda_{exc} = 488$ nm, SL $GaAs_{0.6}/AlAs_5$) and the calculated Raman spectra of GaAs islands (left) grown on (2×4) reconstructed (001) AlAs surface [5] (right).

surface. To find the shapes of the GaAs islands formed on (001)-(2×4) reconstructed AlAs surface, the calculations of the phonon spectra of the islands of various shapes were carried out. The calculations of the phonon frequencies and the vectors of atomic displacements had been made within the Born approximation. The consideration of the long-range Coulomb interaction had been carried out in dipole approximation within model of "rigid ions". The Raman spectra were calculated using the bond polarisability model of Wolkenstein. The GaAs islands shapes were chosen on a basis of a known model of the island nucleation on (2×4) reconstructed (001) surface [5, 7]. The phonon spectra and the Raman spectra in $Z(XY)\bar{Z}$ geometry of the islands of various shapes were calculated. According to the calculations, the lateral localization of LO-like phonons in GaAs quantum islands leads to appearance of new Raman active modes. The calculations of Raman spectrum of the real $GaAs_{0.6}/AlAs_5$ SL, grown in (001)-(2×4) reconstructed surface and containing GaAs

islands, were carried out with account of scattering from GaAs islands of 10 various shapes.

The contribution of the islands with a specific shape in the total calculated Raman spectrum was determined in approximation of the theoretical spectrum to the experimental one. As one can see in Fig. 2 the calculated spectrum is in remarkable agreement with the experimental one. That is very surprising, but the average GaAs cover calculated from the contribution of the islands of all shapes is occurs to be equal to the experimental one (0.6 ML) with the very good accuracy, although this parameter was not fitted specially. According to the result of the approximation, about 70% of GaAs islands contains less than 18 Ga atoms. This result is in good correlation with the STM data [5, 7] according to which the small islands are the most stable. So, the non-destructive and informative technique for analysis of shapes of subnanometer quantum objects, using Raman spectroscopy and localized phonon spectrum calculations is developed. The lateral localization of optic phonons in GaAs quantum islands and quantum wires was observed using Raman spectroscopy. The lateral localization takes place when the GaAs islands are separated by AlAs barriers thicker than 2 interatomic dimensions.

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